Characterizing Structural Controls of EGS Candidate and Conventional Geothermal Reservoirs in the Great Basin: Developing Successful Exploration Strategies in Extended Terranes

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Track Name: Tracers and Exploration Technologies

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Overview

• Timeline
  • Initiation: 1/31/10, Funds Arrived 3/16/10, end date: 1/31/2013

• Budget
  • Project funding: $1,170,505 total; $935,505 (DOE); $235,000 (awardee)
  • FY10: ~$390,000
  • Leveraging significant match from UNR (Faulds), USGS STATEMAP funds for geologic mapping, and collaboration with industry

• Barriers
  • Ability to assess potential EGS resources, prioritize potential EGS sites, and achieve acceptable levels of site selection risk ahead of expensive drilling
  • Inadequate measuring techniques and knowledge preclude low-risk options to effectively select sites and characterize their physical parameters as potential EGS reservoirs before stimulation

• Partners (>30 yrs collective experience in geothermal studies)
  • University of Nevada, Reno (PI-James Faulds; co-PI’s-Mark Coolbaugh, Nick Hinz, John Bell) – all with substantial experience analyzing geothermal systems
  • Helmholtz Center, GFZ, Potsdam, Germany (Dr. Inga Moeck) - > 5 yrs experience in analyzing + modeling geothermal systems
  • Private consultant, gravity surveys – 25 yrs experience
Relevance/Impact of Research:

**Background**

- **Tectonic Setting**
  - Broad region of high heat flow, but geothermal activity focused in NW Great Basin
  - Walker Lane – ~20% of plate motion
  - Dextral shear at NW end transferred to NW-directed extension
  - Transtensional to extensional domain
  - Volcanism generally ceased in middle to late Miocene

- **Geothermal belts = Loci of extension**
  - But details of favorable structural settings not well defined
  - Limited guides for exploration and targeting well sites
  - Many undiscovered blind geothermal systems

Blackwell and Richards, 2004
Relevance/Impact of Research: Background

- **Exploration Challenges**
  - Hot dry wells
  - Overturn in down-hole temperature gradients
  - Wet cool wells
- **EGS one answer**
- **But also need better conceptual models to guide exploration**

Desert Peak, Nevada

Blue Mt., Nevada

Brady’s, Nevada
Relevance/Impact of Research: Project Objectives

- Develop catalogue of favorable structural environments and models
- Improve site-specific targeting of resources through detailed studies of representative sites
- Compare structural controls and models in different tectonic settings
  - Basin and Range
  - Cascades
  - Walker Lane
  - Magmatic vs. nonmagmatic
  - High vs. low temperature
- Synthesize data
- Develop methodologies for enhancement of exploration strategies
  - Reduce risk of drilling non-productive wells in conventional systems
  - Selecting best sites for stimulation in EGS systems
Previous Accomplishments/Scientific Approach

• Previous research initiated characterization of favorable structural settings in western Great Basin (since 2002)
  – Detailed studies – 8 sites
  – Reconnaissance – 10+ sites
  – 23 papers, 4 geologic maps, 2 M.S. theses, 3 senior theses
  – Facilitated development at Salt Wells, Desert Peak, Blue Mt
  – Facilitating anticipated development at Pyramid Lake, Hawthorne, Desert Queen, and San Emidio

• Approach – More robust analyses needed
  – Comprehensive structural inventory
  – Comparative analysis of structural controls
  – Select representative sites for detailed analysis
  – Quantitative approach to elucidating fluid pathways, including slip tendency analysis and 3D modeling of systems
  – Enhance strategies
    • Exploration for undiscovered sites (blind)
    • Expansion of conventional systems
    • Best sites for EGS development
Review Criteria: Technical Merit and Innovation

• Combine conventional and modern techniques
  – Detailed geologic mapping
  – Structural analyses
  – Gravity studies
  – Integrating other geophysical data

• Innovative approaches
  – Slip tendency analysis of faults and fractures at both regional and local scales
  – 3D modeling of key systems
  – Generating 3D geologic maps

• Utilizing Great Basin as natural laboratory to elucidate 4D evolution of geothermal systems
Scientific/Technical Approach: Methods

- Detailed mapping
- Structural analysis
  - Fault kinematics
  - Stress determinations
- Studies of surficial geothermal features
- Gravity surveys
- Integrate available geophysics
- 3D Modeling
Scientific/Technical Approach: Case Study

- **Desert Peak**
  - Blind reservoir-218°C
  - 12.5 MWe flash plant
  - Potential-further development
  - Stepover in normal fault zone
  - Multiple fault splays produce subvertical conduits of highly fractured rock
  - Provide avenue for fluids
Most fields not on major faults
Most on less conspicuous normal faults
Most common occurrences
  – Discrete steps in normal fault zones
  – Terminating, horse-tailing faults
  – Overlapping opposing fault zones
  – Intersecting faults – dilational
  – Small pull apart in strike-slip faults
Indicative features
  – Steps in range fronts
  – Interbasinal highs
  – Ranges of low discontinuous ridges
  – Lateral terminations of mountain ranges
In situ stresses: $\sigma_V=104$ MPa, $\sigma_{H_{\text{max}}}=97$ MPa, $\sigma_{h_{\text{min}}}=53$ MPa; $P_p=42$ MPa

Effective stresses: $\sigma_{V_{\text{eff}}}=62$ MPa, $\sigma_{H_{\text{maxeff}}}=55$ MPa, $\sigma_{h_{\text{mineff}}}=11$ MPa;

Hoek-Brown strength parameters for a moderately fractured rock: $m=2.301$ and $s=0.00198$; UCS=80

All Figures from Moeck et al. 2008
Faults with high shear stress and high slip tendency

Potential fluid flow along critically stressed faults

Assessment of reactivation potential of faults with high slip tendency
**Scientific/Technical Approach: 3D Modeling Results**

**3D Model Permits**

- Subsurface fault geometries
- Cross sections – any orientation, multiple slices
- Stress modeling – favorable fluid pathways
  - Near surface
  - At depth
- Determine slip and dilation tendency – faults and fractures of various orientations
  - Fluid flow paths
  - Induced seismicity
- Field optimization by understanding fluid flow
- Basis for selecting future well sites and paths

**From Moeck et al. (2005)**
Project Management/Coordination

- Year 1 (Regional Assessment)
  - Recruit-add students to research team
  - Structural inventory
  - Compile different settings
  - Regional slip tendency analysis
  - Initiate detailed studies

- Milestones (Year 1)
  - Preliminary structural catalogue (3/2011)
  - Favorable settings defined (1/2011)
  - Regional slip tendency map (1/2011)
  - Students initiate thesis research (8/10)

- Project Reporting (all 3 years)
  - Faulds coordinates all quarterly and annual reports
  - Subcontractors provide quarterly reports
  - Several meetings of research team/year

- Leveraged UNR match, industry support, USGS STATEMAP funding (all years)

- GBCGE staff ensures data from project incorporated in National Geothermal Data System (all years)
Year 2 (Detailed Investigations)

- Selection of 5-6 sites for detailed studies using following criteria:
  - Quality of exposure
  - Geothermal surface manifestations
  - Potential for development
  - Available data
  - Type of system

- Detailed Studies
  - Geologic mapping
  - Delineate reservoir hosts
  - Structural analysis-fault kinematics + stress determinations
  - Geochronology
  - Gravity Surveys
  - 3D modeling
  - Slip tendency analysis
  - GIS Database compilations

- Develop geothermal exploration course

Milestones

- Complete detailed analyses of 3 representative sites (3/2012)
- Embellish catalogue (1/2012)
- Several additional papers (3/2012)
- Teach geothermal exploration course (Spring 2012)
Year 3 (Detailed Investigations & Synthesis)

- Detailed analyses continue
- Comparative analysis of different systems in different settings
- Completion of structural catalogue
- Development of exploration strategies

Milestones

- Complete detailed analyses of 2-3 additional representative sites (1/2013)
- Publish catalogue of favorable structural settings (3/2013)
- Revise geothermal potential maps based on findings (1/2013)
- Prepare papers (3/2013)
  - Systems studied in detail
  - Comparative analysis
  - Exploration strategies
Expected Outcomes/Future Directions

• Expected Outcomes – Deliverables
  – Catalogue (NBMG report) and accompanying peer-reviewed paper describing favorable settings
  – Several papers – structural controls of representative systems studied in detail
  – Published geologic maps of systems studied in detail
  – Comparative analysis paper
  – Geothermal exploration course
  – Infusion of techniques (structural analysis, 3D modeling, etc.) into industry with training of next generation (grad students)
  – Validation of innovative exploration techniques
  – Enhance exploration strategies in extended terranes (conventional + EGS)

• Future Research
  – Expand detailed studies to better define various structural controls
  – Incorporate cost-effective 3D modeling and slip tendency analysis as standard techniques in geothermal exploration
  – Investigate other tectonic settings – e.g., magmatic arcs
  – Applications to understanding induced seismicity in EGS systems
  – Linking processes of active geothermal systems with those in epithermal mineral deposits
Main objectives
- Develop catalogue of favorable structural settings
- Improve site-specific targeting of resources through detailed studies of representative sites
- Compare structural controls and models in different tectonic settings
- Synthesize data
- Develop methodologies for enhancing exploration strategies

Experienced PI’s

Methods
- Detailed geologic mapping
- Structural analysis
- Gravity surveys
- Integrate other geophysical data
- Slip tendency analysis
- 3D modeling

Systematic work plan
- Year 1 – Regional assessment
- Year 2 – Detailed investigations
- Year 3 – Detailed studies + synthesis

Significant potential impacts
- Training next generation in modern-innovative techniques
- Refinement of exploration strategies
- Enhancing understanding of hydrothermal processes